STRATIGRAPHY AND PALYNOLOGY OF THE PERMIAN AT WATERLOO BAY, YORKE PENINSULA, SOUTH AUSTRALIA

by C. B. FOSTER*

Summary

FOSTER, C. B. (1974).—Stratigraphy and palynology of the Permian at Waterloo Bay, Yorke Peninsula, South Australia. *Trans. R. Soc. S. Aust.* 98(1), 29-42, 28 February, 1974.

The discovery of Permian and reworked Devonian microfloras in glacigene sediments from the Troubridge Basin led to a detailed study of the stratigraphy and palynology of the Waterloo Bay area. Quantitative palynological analyses indicate one microfloral assemblage which is equated with Evans' (1969) "Stage" 2 microflora and is of Early Permian age. As a result these sediments have been correlated with other Permian deposits in southern, eastern and western Australia. A biofacies study indicates a low salinity palaeoenvironment which most probably resulted from deglaciation coinciding with a marine transgression that was affecting Southern Australia at this time.

Introduction

Palynostratigraphic correlations with other Permian deposits of Australia have resulted from the recovery of Permian, and reworked Devonian, miospores from sediments of the Waterloo Bay area (Fig. 2). The sediments of the Troubridge Basin are regarded as glacigene deposits (Ludbrook 1969a). Field observations and a biofacies analysis presented in this paper support this and the consequent overall palaeogeographic setting.

The first record of a Permian microflora within the Troubridge Basin (Fig. 1) was given by Cookson (1955, p. 57) when she reported reworked palynomorphs in a deposit of "probable Eocene age". More recently, Harris & McGowran (1971) recorded for the first time *in situ* Permian miospores. One sample collected from the Waterloo Bay area yielded a particularly well preserved assemblage. The purpose of this study was to re-examine the section containing this assemblage. This involved detailed mapping and precise stratigraphic sampling. Samples collected yielded palynomorphs and Foraminifera; no other fossil groups were found. Subsurface material from the Peesey Swamp bore, PDH No. 1, provided moderately well preserved assemblages allowing an intrabasinal correlation. This was in contrast to the subsurface material examined by Harris & McGowran which was poorly preserved. Bore locations are shown in Fig. 1.

Methods

Cliff sections were measured using a Jacob staff with a sighting attachment (Kottlowski 1965). Working from the water's edge, it was possible using Tide Tables (S.A. Dept. Marine & Harbours 1972) to calculate the height of the base of the cliff sections above mean sea level. This provided the "datum" shown in Fig. 2. Section locations were plotted on a base map prepared from air photographs (S.A. Dept. Lands, Svy.962: 2549, 2535) and section heights checked with the Edithburgh Topographic Map (Sheet 828; S.A. Dept. Lands). A 7 cm diameter "post hole digger" was used for field sampling to obtain less weathered samples at depth (max. 1.2 m).

Palynological samples were prepared by treatment with hydrofluoric acid to remove silicates. Excess organic material was then removed using warm Schulze solution followed by alkali. The use of heavy liquid density separations ($ZnBr_2$; S.G. 1.98–1.6) and ultrasonic cleaning improved the yield. Samples

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examined for Foraminifera were processed using standard techniques (Glaessner 1945).

Palynological residues and strew slides deposited in the South Australian Geological Survey Palynological Collection are prefixed "S". Slide coordinates given are from a Leitz Laborlux microscope No. 579756 housed at the Survey.

Locality

The study area, 16 km SW of Edithburgh, occurs as upthrown fault blocks (Wopfner 1970) and forms the southwestern part of the

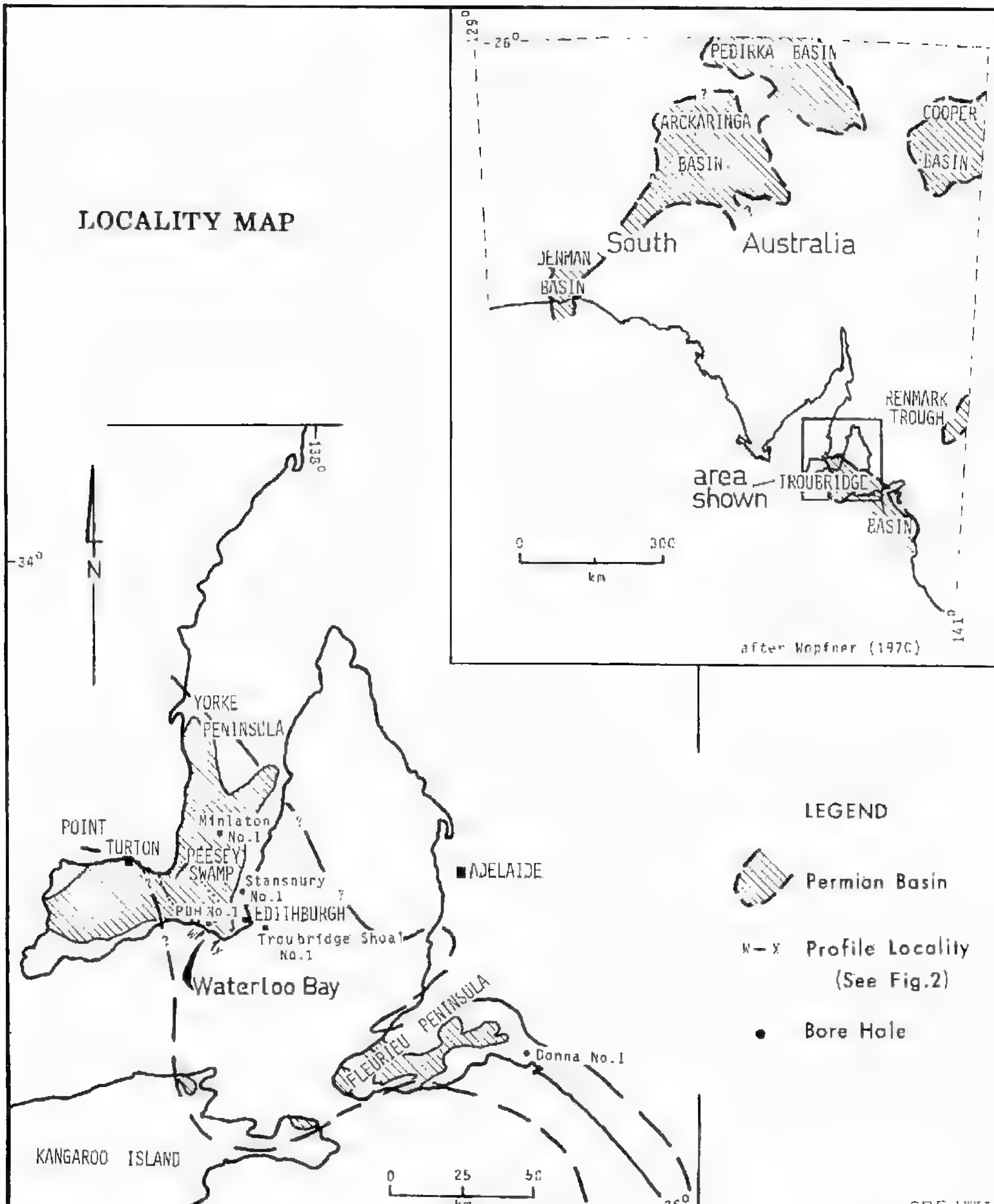


Fig. 1. Locality map.

Troubridge Basin, as defined by Wopfner (1969). It is gently undulating with salt lakes occupying many of the low lying areas. The existence of these lakes, many with scattered erratics about their margins (Howchin 1900), infers the ubiquity of the underlying Permian clays. A thick calcrete capping obscures the geology of the area except in coastal sections where maximum thicknesses of 31 m are exposed. Large erratics and boulder trains litter much of the beach area. Pink garnetiferous sands, which have been associated with glacigene deposits (Coats 1962), occur in high concentrations along parts of the beach.

Stratigraphy

Columnar stratigraphic sections and the coastal profile of Waterloo Bay are shown in Fig. 2.

Permian

The lowermost outcrop, a brown gritty siltstone containing erratics, occurs at beach level and is poorly exposed. Small-scale slump structures were observed, although elsewhere there is no evidence of bedding. Samples collected from this level were barren.

Overlying this, and forming the base of the cliff sections, are black to blue-grey, sandy, micaceous clays. They are carbonaceous in part and on weathering appear grey-white. The sand fraction is poorly sorted and ranges from clear, angular to frosted, well rounded grains. Maximum thickness of the unit is 12 m. Small erratics (3 cm^2) of granitic, gneissic and quartzose composition are scattered throughout. These are smaller than the erratics on the beach, which have been reworked to form modern lag deposits. The sediments are moderately indurated, but lack the fissility typical of shales and the compactness of mudstones; consequently they are referred to as claystones (Pettijohn 1957). Samples yielded a well preserved microflora and a few arenaceous Foraminifera.

Interbedded within the claystones are discontinuous sand lenses, which include fine grained light blue to white and coarse red sands. The origin of these sands is not known, although R. P. Harris (1971, unpublished B.Sc. Honours Thesis, University of Adelaide) has suggested that they are wind blown. Samples collected from these lenses for foraminiferal analysis were barren. Many of the lenses exhibit prominent ferruginous concretionary structures, up to 1 m in diameter; these are most probably weathering features. Generally the contact between the claystones and the sand is sharp; at one locality (Section 8, Fig. 2), the lens overlies a cobble bed (40 cm thick) but it is not traceable for more than 2 m. The bed could represent Permian reworked sediments forming a channel deposit. Similar lag deposits were seen at Point Turton (Fig. 1).

Much of the unit is severely ironstained which gives the outcrop a grey/orange mottled appearance. This apparent lateritization (Crawford 1965) could be a post-Permian surface feature, Ludbrook (1965), however, records iron-staining in subsurface material. Reynolds & Johnson (1972) have reported chemical weathering (lateritization) in a recent subglacial environment, and so the possibility of this being a Permian feature cannot be discounted.

A comparison of the outcrop with the lithologies logged from the Stansbury No. 1 and Minlaton No. 1 Stratigraphic bores (Ludbrook 1965) places the claystones high within the local Permian section and includes them within the Cape Jervis Beds (see also Ludbrook 1969b).

?Permian Clays and Sandstones

Clays, which are mottled reddish green, occur mainly as slope cover. The heavily weathered nature of the unit obscures its boundary contacts (max. thickness 5 m).

Sandstones, which consist of grey white, ill-sorted, poorly indurated clayey sand with small erratics. Where it is not in direct contact with the sea (e.g. Section 8), it weathers to form peculiar columnar structures. These appear to be the result of two sets of "jointing"; the earlier horizontal set could be following bedding planes with the latter set perpendicular to the first. Maximum thickness 4 m.

Samples collected from these units were barren and considering the possibility of post-Permian reworking their exact age is not known. An essentially similar outcrop to that of Section 8 was found at Port Moorowie (Sections 2 and 3) and has been mapped as "Permian" by Crawford (1965).

Tertiary

These are horizontally bedded, buff to pink, polyzoal limestones (Section 10) that have been sporadically calcreted. They form resistant headlands for 2 km along the coast to Troubridge Hill. Underlying the calcrete the pinkish limestone is strongly recrystallised and shows numerous irregular solution cavities. Below this level the unit becomes less recrystal-

lised and contains distinctive buff coloured "sub-units". Angular quartz gravel bands grading upwards to coarse brown iron-stained sands occur at several intervals throughout the unit. Maximum thickness 24 m.

Foraminifera from samples of these less indurated sub-units indicate a Late Eocene age and suggest correlation with Rogue Formation and basal Port Willunga Beds (J. M. Lindsay, 1972, S.A. Department of Mines, unpublished report, RB 72/190).

The Pliocene Hallet Cove Limestone, which Crawford (1965) has shown to occur at Point Gilbert, was not found at this locality.

Ardrossan Clays and Sandrock (Crawford 1965)

The maximum thickness of the unit at this locality is 1.7 m. This includes the mottled green-brown sandy clays containing grit bands and deeply weathered erratics and the unconformably overlying red-brown clays with their distinctive "alunite and/or kaolinite" bands (Crawford 1965, pp. 40-41).

X-ray diffractometer (X.R.D.) analysis of samples collected from these bands indicated mainly illite (R. J. Love, personal communication). A similar lithology was sampled at the Tertiary/Permian contact (Section 10) and X.R.D. analysis showed a similar clay mineralogy to that from the Quaternary sequence. Therefore, it is most likely that these bands are a post-depositional feature.

Quaternary Aeolianite and Calcrete

Aeolianite, the maximum exposure of this grey-white poorly indurated calcarenite (8 m), occurs where it forms a prominent headland and an associated wave-cut platform (Section 5, Fig. 2). This is the only section which exhibits large scale cross-bedding. Elsewhere in the profile the unit is horizontally bedded but is easily identified by its distinctive "swallow hole" weathering pattern. Planktonic and benthonic Foraminifera recovered by Lindsay (1972, cited above) from a well bedded buff calcarenite (1 m thick) contained within the aeolianite sequence (Section 5) were considered by Lindsay to indicate a Late Cainozoic age and identification as Bridgewater Formation (Firman 1969).

Calcrete, of varying thickness (up to 8 m), and in part underlying the aeolianite, forms a blanketing surface seen in all sections. In places it was possible to identify up to five distinctive "beds" which were of limited lateral extent. One such "bed" (0.8 m, Section 8) consisting of black, rounded to angular fragments within a light green calcareous matrix, could be traced for 10 m before becoming "absorbed" into the more massive featureless calcrete to the east and faulted out to the west. The unit is sandy and friable at the base becoming more nodular to massive at the top.

Taxonomic List of Permian Microflora

Forty-six species, from thirty genera, of Permian palynomorphs were identified from ten samples. Sample locations *not* shown on Fig. 2 occur away from the sections illustrated. Precise locations of all samples accompany the slides deposited at the Geological Survey. Fifty-two strew slides were examined; selected species are figured. The miospore genera are arranged alphabetically within the classificatory scheme proposed by Potonié (1956 and subsequent publications) and its emendations, especially those of Dettmann (1963).

Where necessary, brief notes on taxa have been included; the descriptive terminology used is in keeping with Kremp (1965). Disaccate measurements are in accord with Segroves (1969, Fig. 1, p. 176).

Quantitative microfloral data and the chronostratigraphic significance of the Waterloo Bay Assemblage are discussed later in the paper.

Anteturma SPORITES H. Potonié 1893

Turma MONOLETES Ibrahim 1933

Suprasubturma ACAVATOMONOLETES Dettmann 1963

Subturma **AZONOMONOLETES** Luber 1935

Laevigatosporites flexus Segroves 1970 (Fig. 14)

Laevigatosporites sp.

Tuberculatosporites modicus Balme & Hennelly 1956

Turma TRILETES Reinsch, emend. Dettmann 1963

Suprasubturma ACAVATITRILETES Dettmann 1963

Subturma **AZONOTRILETES** Luber, emend. Dettmann 1963

Acanthotriletes tereteangulatus Balme & Hennelly 1956

Apiculatisporis levis (Balme & Hennelly) Segroves 1970

Apiculatisporis sp. (Fig. 8)

Trilete, laesurae extending to equator and sometimes bifurcating at termini. Lips developed 0.5 μm wide and unsculptured. Amb round to oval, boundary uneven. Sparsely spaced broad coni (1–2 μm wide) are arranged concentrically on the distal face. Diameter (10 specimens) 18–37 μm.

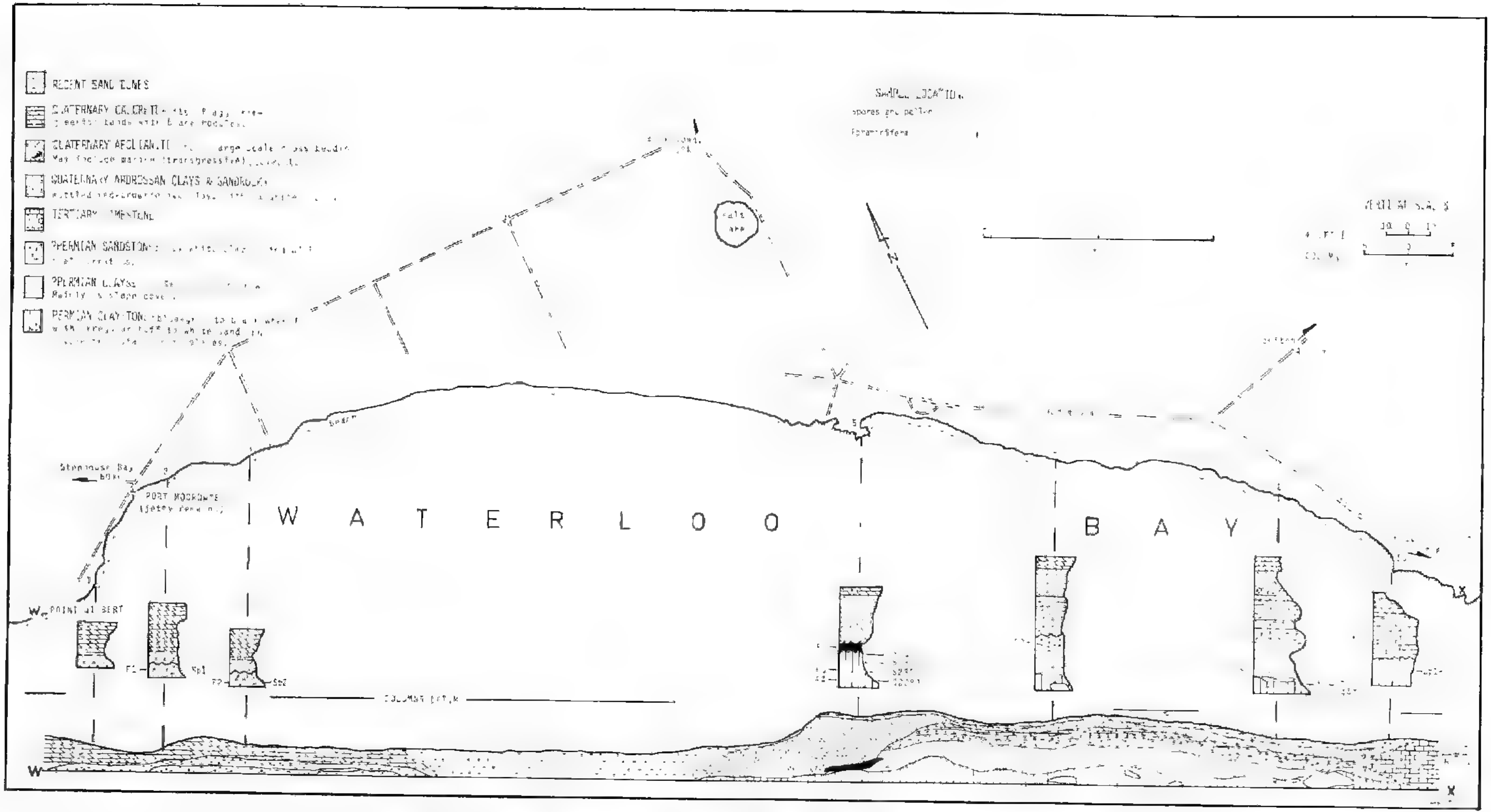


Fig. 2. Columnar stratigraphic sections and coastal profile, Waterloo Bay.

Baculatisporites sp.
Calamospora diversiformis Balme & Hennelly 1956
Calamospora sp. cf. *C. microrugosa* Schopf, Wilson & Bentall 1944
Deltoidospora directa (Balme & Hennelly) Norris 1965
Densoisporites solidus Segroves 1970
Granulatisporites sp. cf. *G. trisinus* Balme & Hennelly 1956
Granulatisporites trisinus Balme & Hennelly 1956
Horriditriletes ramosus (Balme & Hennelly) Bharadwaj & Salujha 1964
Krauselisporites sp.
Leschikisporis vestus Segroves 1970
Lophotriletes sp. (Fig. 11)

Trilete, triangular amb with strongly developed concave sides, paralleling the laesurae. Raised lips (1 μm) slightly thickened. Exine 1 μm thick supporting on the distal surface and at the equator small blunt cones (2 μm high, 1 μm apart) and spines 2-4 μm, 1.5 μm apart. Ornament lacking on proximal face. Diameter 35μm. Differs from cf. *L. rarus* Bharadwaj & Salujha 1964 by the strong concavity of the amb and the increased ornament, but lacks the thickened interradial areas of *L. novicus* Singh 1964.

Microbaculispora tentula Tiwari 1965
Punctatisporites gretensis Balme & Hennelly 1956
Punctatisporites sp. cf. *P. gretensis* (Fig. 7)

In all regards this form resembles *P. gretensis*, except in size. Av. diameter 20 μm cf. 118 μm of the latter. The exine, 2 μm, is thicker than that of *P. minimus* de Jersey 1960.

Verrucosisporites sp.

Anteturma POLLENITES R. Potonié 1931
Turma PLICATES Naumova 1939
Subturma **MONOCOLPATES** Iversen & Troels-Smith 1950

Cycadopites cymbatus (Balme & Hennelly) Segroves 1970
Marsupipollenites triradiatus forma *triradiatus* Balme & Hennelly 1956

Turma SACCITES Erdtman 1947
Subturma **MONOSACCITES** Chitaley emend. Potonié & Kremp 1954

Parasaccites gondwanensis (Balme & Hennelly) Segroves 1969 (Fig. 16)
Parasaccites sp. A (Fig. 17)

Monosaccate, trilete scar ruptured on several specimens. Distal saccus attachment overlaps 1/3 of corpus diameter. Amb triangular, with undulant margin. Corpus rounded triangular in shape. Sacci brochi elongate, 0.5–1 μm in diameter. Dimensions (3 specimens): T.D. 60 μm, C.D. 30 μm. This species differs from *V. triangularis* (Mehta) Lele 1964 in that the corpus is roundly triangular and not circular.

Parasaccites sp.
Parasaccites sp. cf. *V. Mehtae* Lele 1964
Parasaccites diffusus Tiwari 1965
Potonieisporites balmei (Hart) Segroves 1969 (Fig. 9)
?*Hoffmeisterites* sp. (Fig. 19)

Monosaccate. Amb oval, corpus sub-circular with marginal folds. Trilete mark not seen. Saccus attachment is equatorial and subequatorial. Dimensions: longitudinal axis 160 μm; transverse axis 100 μm; corpus diameter 75 μm.

Subturma **DISACCITES** Cookson 1947

Alisporites gracilis Segroves 1969
Limitisporites moersensis (Grebe) Klaus 1963 (Fig. 13)
Limitisporites sp. cf. *L. rectus* Leschik 1956 (Fig. 21)

Differs from *L. rectus* being somewhat larger; total breadth 76 μm, breadth of corpus 42 μm; saccus length 38 μm, corpus length 46 μm; cappa width 26 μm.

Protohaploxypinus rugatus Segroves 1969
Striatoabieites multistriatus (Balme & Hennelly) Hart 1965 (Fig. 5)
Sulcatisporites sp.
Sulcatisporites sp. cf. *S. splendens* Leschik 1956 (Fig. 18)
Vittatina sp.

Incertae Sedis
Group ACRITARCHA Evitt 1963
Subgroup **ACANTHOMORPHITAE** Downie *et al.* 1963

?*Baltisphaeridium* sp. (Fig. 12)
Micrhystridium spp.

Subgroup **POLYGONOMORPHITAE** Downie *et al.* 1963

Veryhachium spp. (Fig. 10)

Subgroup **NETROMORPHITAE** Downie *et al.* 1963

Leiofusa spp. (Fig. 15)

Algae

Botryococcus braunii Kützing 1849 (Fig. 6)

Composition of Palynological Assemblage

No significant quantitative changes in miospore composition were recorded from any of the samples (see Fig. 3). Unfortunately, spores from the upper samples in Peesey Swamp No. 1 (10.6 m–45 m) were too poorly

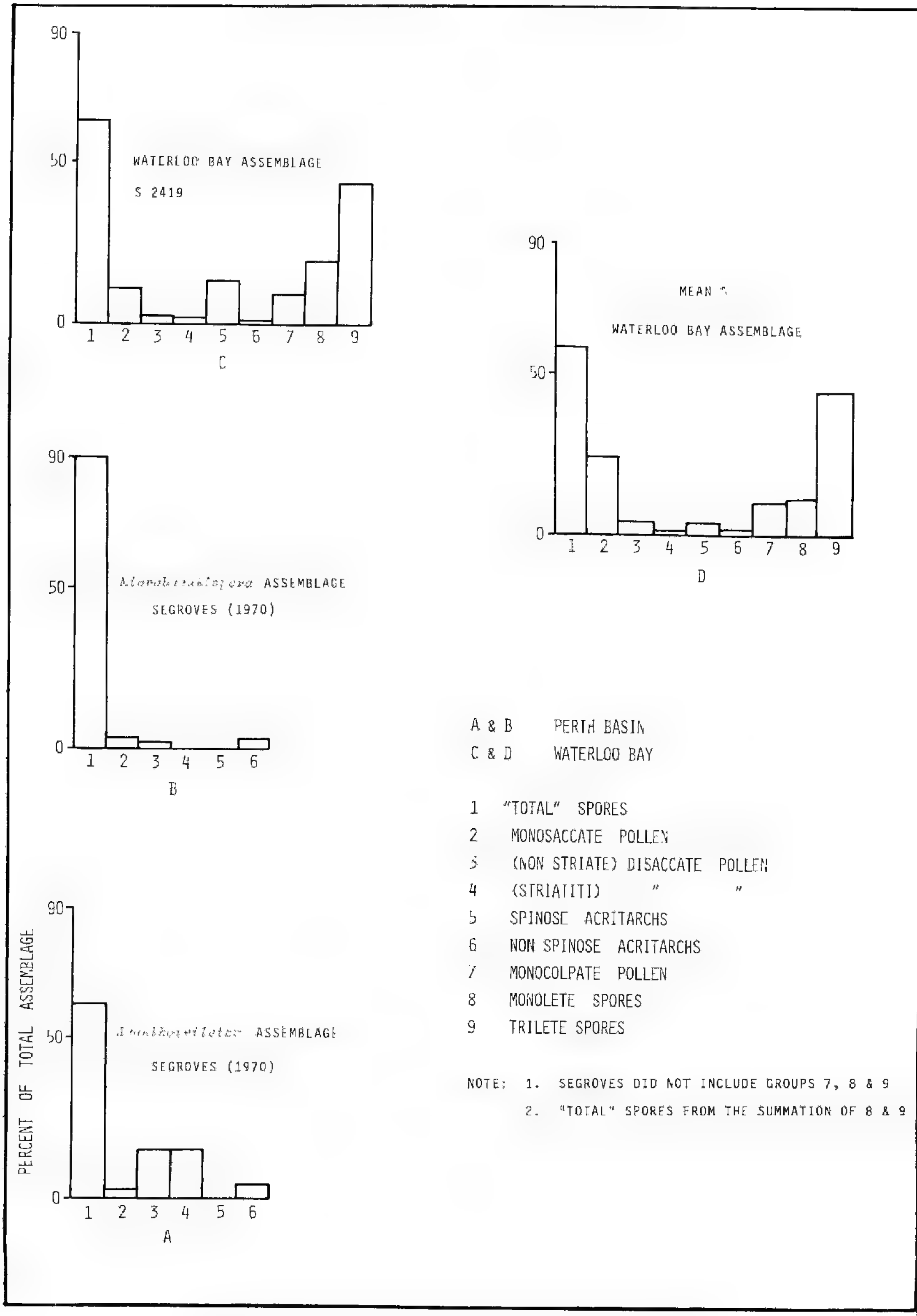


Fig. 3. Quantitative comparison of microfloral assemblages.

preserved to allow any firmer conclusions other than that the assemblage is of Permian age. Consequently, only one microfloral assemblage is considered to be present.

This well preserved, moderately diverse assemblage is dominated by monosaccate pollen including *Potonieisporites balmei* and *Parasaccites* spp. (av. 20%, max. 30%). Monoculpate pollen, *Cycadopites cymbatus*, is also abundant (5–10%) as is the trilete spore *Microbaculispora tentula* (12%). Non-striate bisaccates form a minor element of the assemblage (3%) and striate bisaccates are rare (<1%). Four genera of spinose acritarchs are present (up to 13%) and include *Veryhachium*, *Micrhystridium*, and *Leiofusa*. Percentages are based on a total count of 1,600 specimens.

Apart from these elements, a well preserved reworked Middle to Late Devonian microflora (up to 2%) is present, including *Geminospora lemurata* Balme, *Convolutispora fromensis* Balme & Hassell, and *Ancyrospora* sp. Fungal spores, algae, *Botryococcus braunii*, and wood fragments form a minor background element. No megaspores were found.

Biostratigraphy and Age

The Australian Permian microfloral sequence has been subdivided into various palynostratigraphic zones. Evans (1969), working in southern and eastern Australia, erected a five-fold subdivision ("Stages" 1–5) which he considered ranged from Late Carboniferous through to Late Permian (Stages 2–5). He related these Stages to the early work by Balme (1964) in Western Australia. Paten (1969) re-subdivided Stages 4–5 into six sub-stages on material from the Cooper Basin (South Australia). More recently Segroves (1970) produced five assemblage zones within the Permian sequence of the Perth Basin. The relationship between these schemes is shown in Fig. 4. Although the late Early to Late Permian subdivisions do not apply to this study, they have been included for completeness.

Recognition of these subdivisions is based upon the first appearances of key species and the quantitative composition of the assemblage (in particular Segroves 1970; this study). Problems exist using this approach because of facies variations (Balme 1969; see later), and in many cases the precise stratigraphic ranges of the key species are not known. Negative evidence such as the absence of a particular Stage indicator within a well preserved assemblage is often used to preclude it from being younger than that Stage. This approach may not be desirable and it reflects the need for further study of the Australian Permian. The writer is currently engaged in research into these problems in the Bowen Basin, central Queensland.

Correlation

The Waterloo Bay Assemblage may be compared with Evans' (1969) assemblages ("Stages") and with those of Segroves (1970). The correlation using both works is shown separately and the differences are discussed.

Two species, *Deltoidospora directa* and *Marsupipollenites triradiatus* forma *triradiatus*, which Evans (1969, Fig. 4) has shown do not occur in assemblages older than his Stage 2, were found in the Waterloo Bay Assemblage. In addition the presence of striate bisaccate forms, e.g. *Protohaploxypinus rugatus*, exclude the assemblage from Stage 1. The absence of *Verrucosisporites pseudoreticulatus*, a Stage 3 index form, within this well-preserved assemblage, is taken to indicate that the microflora is not younger than Stage 2. Consequently, using these criteria the Waterloo Bay Assemblage is equated with Stage 2.

In terms of Segroves' units (1970, text. fig. 2) the Waterloo Bay Assemblage compares closely with that of the "*Microbaculispora* Assemblage" (Stage 2, Evans' units). A quantitative comparison is given in Fig. 3. The slightly higher percentage of striate bisaccate pollen at Waterloo Bay suggests that its microflora is younger than the Perth Basin assemblage, and is therefore correlated with the upper Nangetty Formation, Perth Basin.

However, using the *range chart* (Segroves 1970, fig. 4) the Waterloo Bay Assemblage appears to correlate with the "*Acanthotriletes* Assemblage" (Stage 3 plus lower Stage 4; Evans' units). The species whose ranges indicate this are *Granulatisporites trisinus*, *Tuberculatosporites modicus* and *Laevigatosporites flexus*; and are included with several other species (viz. *C. diversiformis*, *A. teretiangulatus*, *A. levis*) of the ten considered diagnostic of that assemblage (Segroves 1970, p. 514). To check this discrepancy the two microfloras were compared quantitatively (Fig. 3). The Waterloo Bay Assemblage was found to differ from the "*Acanthotriletes* Assemblage" as follows:

(i) The greater abundance of monosaccate pollen.

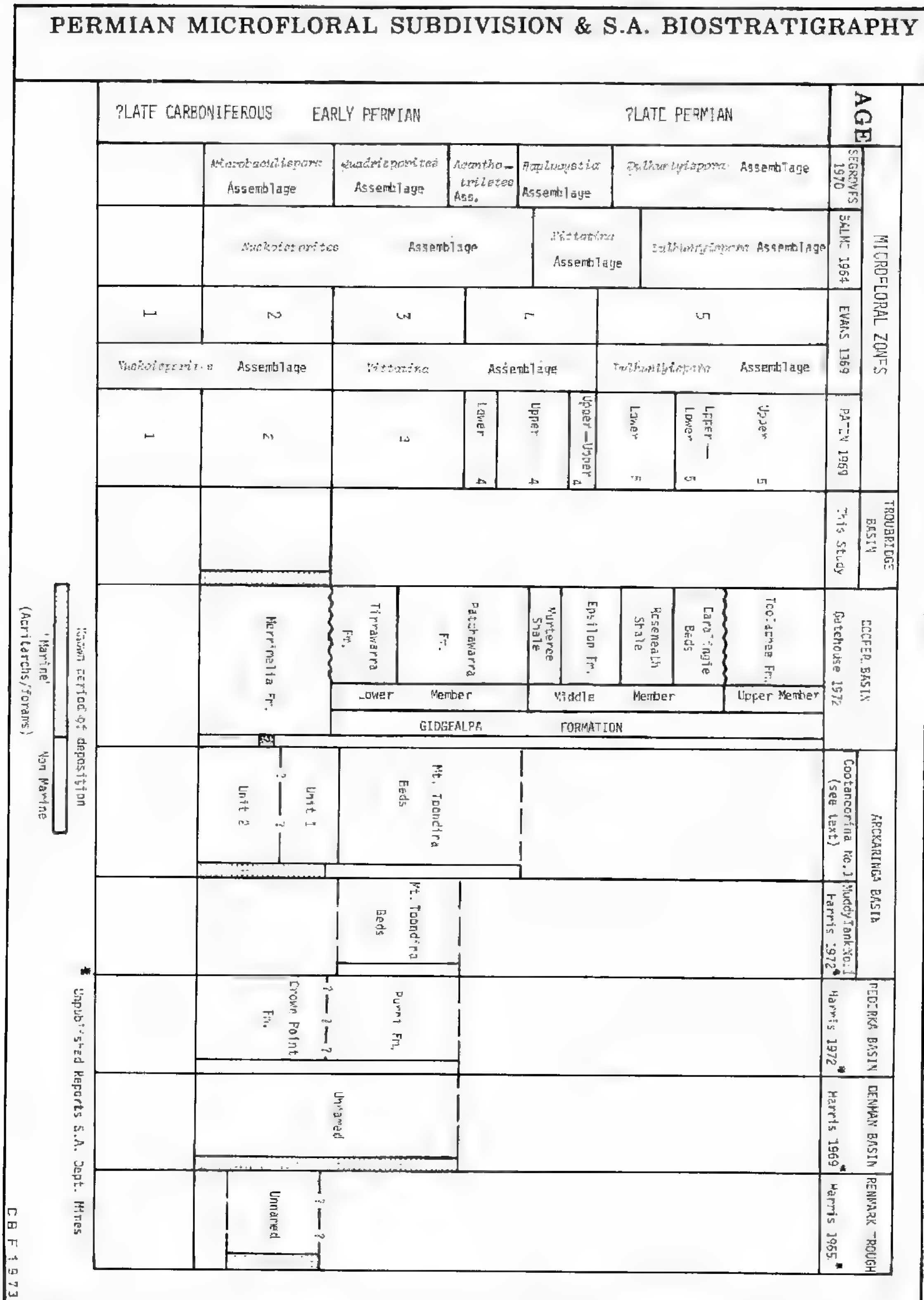


Fig. 4. Permian microfloral subdivision, South Australian biostratigraphy.

(ii) The greater abundance of spinose acritarchs.

(iii) The lower frequency of bisaccate pollen.

The first two can be explained by facies variations, the acritarchs indicating saline conditions, while the monosaccate pollen indicate proximity to the floral source, as their dispersal is effected by wind and water currents (Muller 1959). However, the low frequency of bisaccates cannot be explained by the same reasoning, and is considered significant as they reflect the progression of floral evolution (Balme 1962). Consequently the apparent correlation (i.e. with the "*Acanthotriletes* Assemblage") is rejected. Because of this, the stratigraphic ranges of these three species, mentioned above, presumably extend into earlier Permian strata.

Age

Marine shelly fossils from the Nangetty Formation, Perth Basin, and the Upper Lochinvar Formation, Sydney Basin, both Stage 2 microfloral localities, have been correlated with those from the type Sakmarian (Dickins 1963, 1968a, b) and are accordingly of Early Permian age. The Waterloo Bay Assemblage correlated herein with the Stage 2 microflora is, therefore, of Early Permian age. Moreover the gross microfloral composition of this assemblage, in particular the low percentage taeniate bisaccate pollen, is considered indicative of middle Sakmarian age (Balme 1962; Segroves 1969; Hart 1971).

Although problems in correlating the Australian Permian with the standard Russian sections exist (see Waterhouse 1970), the Standard Stage names are used in this paper to allow rapid comparisons with earlier published works. However, should the recent conclusions of Balme (1973) regarding the position of the Carboniferous/Permian boundary be accepted, the Waterloo Bay Assemblage will be of Late Carboniferous age.

Local Implications

Correlations with other Permian sediments within South Australia are shown in Fig. 4. Such information is useful in palaeogeographic and environmental interpretations. Within the Troubridge Basin the outcrop at Waterloo Bay has been correlated with at least 35 m of Permian sediments intersected (45–80.5 m) in Peesey Swamp No. 1.

The high frequency of reworked, excellently preserved Devonian spores suggests a local origin (Harris & McGowran 1971). Long distance transport along ice movement pathways from areas of proven Devonian sedimentation (e.g. Antarctica, Helby & McElroy 1969) would destroy the palynomorphs, particularly those with delicate appendages such as *Ancyrospora*. This is further evidence of Devonian deposition within the State (see Harris & McGowran 1973).

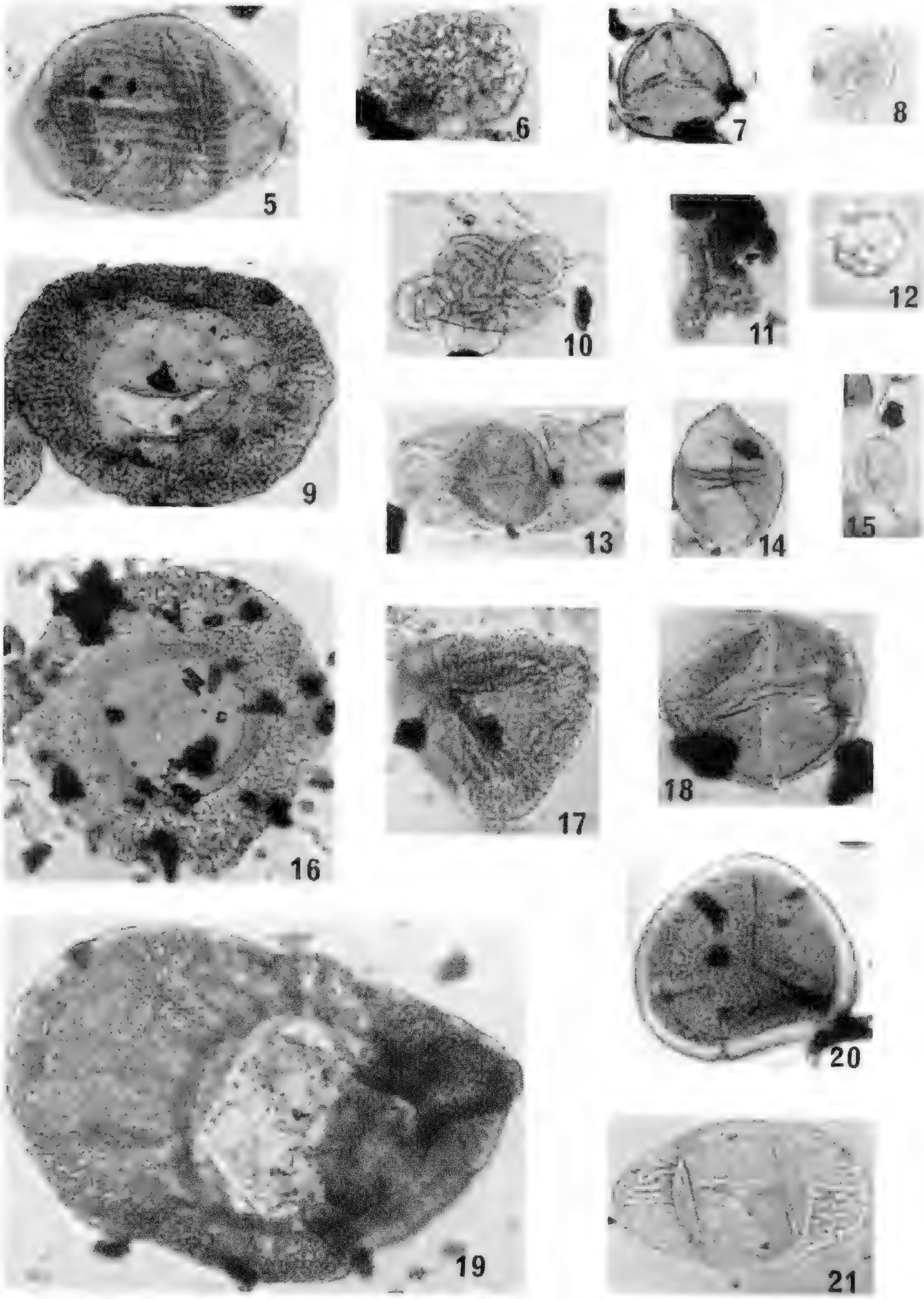
Environment

The following environmental inferences are made from a consideration of the preserved associations of microfossil groups in the Waterloo Bay sediments.

Spinose acritarchs have in general been regarded as indicators of marine conditions or marine influences (Downie, Evitt & Sarjeant 1963). Smith & Saunders (1970, p. 324) demonstrated that acritarchs of the same genera (viz. *Veryhachium*, *Baltisphaeridium*; also see Staplin 1961) as those from Permian sequences are "confined to areas continuously or intermittently open to marine waters and

FIGS. 5-21
All figures x 400.

Fig. 5. *Striatoabietites multistriatus* (Balme & Hennelly) Hart, S 2267/3, 23.8:114.1.
Fig. 6. *Botryococcus ?braunii* Kützing, S 2267/1, 25.5:113.0.
Fig. 7. *Punctatisporites* sp. cf. *P. gretensis* Balme & Hennelly, S 2267/4, 40.8:111.9.
Fig. 8. *Apiculatisporis* sp., S 2441/2, 27.8:110.1.
Fig. 9. *Potonieisporites balmei* (Hart) Segroves, S 2390/1, 32.3:99.8.
Fig. 10. *Veryhachium* sp. (cluster), S 2267/4, 27.0:100.4.
Fig. 11. *Lophotriletes* sp., S 2388/1, 48.0:104.7.
Fig. 12. *?Baltisphaeridium* sp., S 2389/1, 39.0:95.0. (Nomarski Interference.)
Fig. 13. *Limitisporites moersensis* (Grebe) Klaus, S 2267/4, 25.5:110.8.
Fig. 14. *Laevigatosporites flexus* Segroves, S 2267/4, 25.8:110.3.
Fig. 15. *Leiofusa* sp., S 2389/1, 33.0:93.3.
Fig. 16. *Parasaccites gondwanensis* (Balme & Hennelly) Segroves, S 2267/2, 36.8:109.2.
Fig. 17. *Parasaccites* sp. A, S 2419/1, 41.1:112.4.
Fig. 18. *Sulcatisporites* sp. cf. *S. splendens* Leschik, S 2390/5, 30.0:109.1.
Fig. 19. *?Hoffmeisterites* sp., S 2390/5, 39.6:109.6.
Fig. 20. *Geminospora lemurata* Balme (reworked Devonian example), S 2267/4, 99.6:39.[illegible]
Fig. 21. *Limitisporites* sp. cf. *L. rectus* Leschik, S 2388/3, 32.6:92.8.



FIGS. 5-21

do not occur in fluvial deposits". Data from S.A.G. Cootanoorina No. 1 (Arckaringa Basin, Harris & McGowran 1973) are in keeping with this conclusion and suggest a threshold salinity is required for their appearance.

Within the Permian sequence at Waterloo Bay the association of spinose acritarchs and arenaceous Foraminifera is taken to indicate unequivocally marine conditions. Furthermore, a *low salinity* marine environment is inferred from the following:

(1) The presence of *Botryococcus braunii* within the assemblage. This is generally regarded as a fresh water species (Blackburn 1936; Dulhunty 1944) although Cookson (1953) has recorded *B. braunii* from Recent brackish water environments.

(2) The meagre foraminiferal assemblage consisting of only a few specimens (18) of apparently only a single species, *Hemidiscus balmei* Ludbrook 1967, which is a primitive form, for which a low salinity environment seems likely (Harris & McGowran 1971).

(3) The excellent preservation of the miospores, in particular the reworked Devonian forms. Tschudy (1969) has shown that such preservation would best be achieved under low pH, negative Eh conditions where bacterial activity is minor. Such conditions are commonly developed on lake bottoms and in closed basins; i.e. not normal marine situations.

Accordingly it is believed that the Permian sequence at Waterloo Bay was deposited in a low salinity marine or quasimarine environment.

Evidence of Permian glacial activity within the Troubridge Basin, particularly on Fleurieu Peninsula (Fig. 1), has been well documented (see Ludbrook 1969a). At Waterloo Bay glacial influence is indicated by erratics and rare faceted pebbles which occur within the sequence. Accordingly cold climatic conditions are inferred. This view is also maintained by Ludbrook (1967, 1969a) and Harris & McGowran (1971) who have stated that the arenaceous foraminiferal assemblages are also consistent with cold water conditions (see above). Moreover troughs or fiords have been postulated as the sites of deposition of the microfaunas (Ludbrook 1969a).

The diversity of the microfloral assemblage at Waterloo Bay suggests, however, that conditions were not fully glacial and that the climate was becoming warmer. In a comparative study of microfloral assemblages (Stage 2) from Antarctica, South America and Pakistan, Kemp (1973, p. 38) concluded it was likely that the sediments examined "represent a late stage in the glacial history of the areas studied".

An active tectonic environment covering all of southern Australia has been proposed by Wopfner (1970) and McGowran (1973). Both workers have postulated that initial rifting between Australia and Antarctica occurred during this time. Although there is little other evidence from the present study, it is most likely that the sediments were deposited in graben structures formed by syngenetic faulting (see Wopfner 1970). The immediate environment of deposition using this model is the same as that proposed by Ludbrook (1969a), although "Alpine type" glacial features as proposed by Campana & Wilson (1955) would not be present.

Synthesis

From the microfloral evidence it is postulated that the period of glaciation was ending. Syndepositional movement, in particular uplift during deglaciation, rejuvenated erosion and increased sedimentation rates. Rapid rates of sedimentation are supported by the presence of unaltered biotite, which forms a significant part of the micaceous element of claystones (see Wopfner 1970), and the excellent preservation of the reworked Devonian miospores. Such preservation demands rapid recycling within a reducing environment.

There is clear evidence that during this period a marine ingression occurred. It is suggested that inflowing glacial meltwaters appreciably lowered the salinity of the ingressing sea and consequently restricted faunas to arenaceous Foraminifera.

This model, consistent with known sedimentological and palaeontological data, equates the sediments of Waterloo Bay with the second marine shale unit of Wopfner's (1969) three-part lithological sequence for the Permian of South Australia. The youngest unit, generally a fresh water deposit, has not been recorded within the Troubridge Basin.

Conclusions

From the results of a taxonomic study given in this paper, the Waterloo Bay Assemblage is correlated with Evans' (1969) "Stage" 2 microflora (lower Dalwood Group, Sydney Basin) and equated with the "*Microbaculispora* Assemblage" (Nangetty Formation, Perth

Basin). This and the gross quantitative microfloral data indicate a probable Sakmarian (Early Permian) age.

The stratigraphic sequence described is of local importance and includes two Cainozoic discoveries; the dating of the Tertiary limestones at Late Eocene, and a further record of planktonic Foraminifera within the Quaternary aeolianitic sequence.

From a consideration of the palynomorphs and associated arenaceous Foraminifera, a low salinity environment of deposition was concluded. It is thought to have resulted from glacial meltwaters lowering the salinity of an ingressing sea.

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